Observational Signatures of Magnetic Reconnection in the Extended Corona

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*Considerable contributions from K. Reeves & D. McKenzie
Supra-Arcade Downflows (SADs) Observations

- Teardrop-shaped voids observed to travel sunward through the bright, hot fan extending outward along the spine of developing post-flare arcades.

- Observed with high-temperature instrumentation (EUV, X-ray) & white-light coronagraph (density)

- LONG DURATION EVENTS
Supra-Arcade Downflows (SADs) Observations

McKenzie & Savage 2009; Savage & McKenzie 2011
Supra-Arcade Downflowing Loops (SADLs) Observations

Fig 1: Savage & McKenzie 2011
Supra-Arcade Downflowing Loops (SADLs) Observations

Fig 1: Savage & McKenzie 2011

2003 Nov 4, TRACE

Fig 2: Savage et al. 2010

2008 Apr 9, Hinode/XRT

Behind the limb
Supra-Arcade Downflowing Loops (SADLs) Observations

Fig 1: Savage & McKenzie 2011

Fig 2: Savage et al. 2010

Fig 3: Savage et al. 2012
Different from Plasmoid Observations

- Coherent ‘bubble’ of **emitting** plasma held together by magnetic fields.

- Observed with broadband-temperature instrumentation (EUV, X-ray, Hard X-ray) & white-light coronagraph (density)

✓ “First they grow, then they go.” – Lorenzo Sironi
Example Models & Simulations

- Thin flux tubes created during the reconnection process across the current sheet.

- Plasmoids a 3-D product of reconnection concurrent to single loop creation.
SADs + SADLs
SADs + SADLs

- SADs appear to be voids created by loops (SADLs) shrinking through the fan plasma.

Fig 1: Savage et al. 2012
- SADs appear to be voids created by loops (SADLs) shrinking through the fan plasma.

Fig 1: Savage et al. 2012
Supra-Arcade Downflowing Loops (SADLs) Observations

2012 Jan 27, SDO/AIA
Particle Acceleration & Heating

**Fig 1:** Savage – 2010 Nov 3 flare

**Fig 2:**

**Fig 3:**

Savage – 2010 Nov 3 flare

**Fig 1:** Asai et al. 2004 (Khan; Liu)

**Fig 2:**

**Fig 3:** Chen et al. 2014; 2015
Diagram Models

Fig 1:

Fig 2:

Fig 3:

Fig 1, 2: Savage et al. 2012

Fig 3: Ohyama & Shibata 2008
3D is Pivotal

Fig 1, 2: Savage et al. 2012
Fig 3: Ohyama & Shibata 2008
- Basic reconnection scenario, post initial flux rope formation and release.
- General organization of the magnetic field of the various components (SADs, SADLs, plasmoids).
- Field lines reconnect across the current sheet to form outflowing flux tubes while plasmoids form along the current sheet.
- SADs are formed as the flux tubes (SADLs) retract through hot plasma in the fan (otherwise, only SADLs are observed).
Model Constraints

OBSERVED TEMPERATURE AND DENSITY ALWAYS LOWER THAN FAN

Fig 1: Savage, McKenzie, & Reeves 2012

Fig 2: Hanneman & Reeves 2014
Models

a) Pressure pulse + MHD wave
(T >> fan)

b) Reconnection outflows
(T ~< fan)

c) Peristaltic pumping
(T ~< fan)

- Too hot with respect to the surroundings
- Incorrect geometry with respect to observations
- Incomplete, feasible; Difficult to match to observations

Fig 1: Cecere et al 2012
Fig 2: Cassak et al 2013
Fig 3: Scott et al 2013
Rayleigh-Taylor Instabilities behind retracting flux tubes ($T > \text{fan}$)

Too hot with respect to the surroundings  

\textbf{BUT}  

Best match to observations to date (3D!!!) although early in development

Fig 1: Guo et al 2014
SADs in the Extended Corona

Fig 1: Sheeley, Warren, & Wang 2007

Fig 2: Sheeley & Wang 2007
SADs in the lower corona are typically observed well after reconnection has occurred.

In the extended corona, we are better able to observe the migrating reconnection sites.

Coronagraphs allow us to see reconnection develop behind the CME while looking directly at the density.

“Giant Arches” Flare – 2014 Oct 14

PROBA-2/SWAP – 174 Å

~1.45 R☉
SADs in the Extended Corona...

LASCO C2
PROBA-2/SWAP
AIA 131 Å

A: Flattened from a year’s worth of data
   Cleaned (cosmic rays, background stars, planets)
   Attenuated disk

B: Smooth-Differenced
   - Scaled
SADs in the Extended Corona...

LASCO C2
PROBA-2/SWAP
AIA 131 Å

C: Run-Mean-Differenced
D: Smooth-Differenced

- Extracted
- Scaled
SADs in the Extended Corona...

40 Flows Tracked
Median ~ -82 km/s
SADs in the Extended Corona...
SADs in the Extended Corona...

TBD
Correlate flows directly to lightcurve as done for 2010 Nov 3rd event
Thoughts

- Continuation of shrinking loops imparts energy into the current sheet long after the flare. Clearly.
  - But for an entire week??
  - Does this happen all of the time?
  - How did this one grow so large?
    - Density stratification? Active region interactions?

- Reconnection is fast and patchy.

- Add Hinode/XRT and RHESSI data (started).

- Do features track between fields of view both ways?
  - Initial work begun. (Some even in LASCO C3.)

- Need for instrumentation to fill the gap in observing the transition corona
  - Important to be in single wavelength
  - Possibly coming to an International Space Station near you....